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# Material Optimisation for Future Double Skin Façade System Design

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**Abstract.** Façades have a significant impact on energy consumption in interiors. Designers aimed to reduce energy consumption by developing different façade systems. Double Skin Façade (DSF) aims to increase thermal and ventilation performance in the interior. The depth of the cavity gap between the two façade layers with air inside may adversely affect indoor daylight performance. In addition, studies in the literature indicate that this façade system shows optimum performance in cold climates. With the right design decisions, the DSF system can provide optimum performance in hot climates. In building designs with DSF systems in these climate zones, daylight and energy simulations can make the right design decisions. However, the climate crisis (CC) is increasing air temperatures and sunshine hours in hot and arid climate zones. Simulations are based on current climate data, and the recommendations obtained may not show optimum performance in the future. The study aims to propose an educational building model with a DSF system that will provide optimum visual comfort for 50 years in the Mediterranean climate type (CSA). Meteonorm has created weather scenarios for Izmir for 2050 and 2080. Opossum and Galapagos carried out the optimisation process using this data. The study proposes models that will perform optimally in Izmir for 50 years.

## 1. Introduction

With the development of technology, double skin façade (DSF) systems are beneficial in improving thermal comfort and ventilation conditions in indoor spaces. They involve a transparent second shell in front of the building façade [1]. Designers frequently use the DSF system in educational buildings due to the ease of ventilation and heating. This façade system has positive effects, such as the homogeneous distribution of daylight in the interior [2]. The cavity gap depth further distances the dark wall of the room from the window. According to Chartered Institution of Building Services Engineers (CIBSE), daylight access to the farthest point of the interior becomes more complex as it moves away from the window [3]. So, the literature explains the effects of the DSF system on indoor visual comfort.

The climatic suitability of the DSF system is an effective parameter of indoor daylight performance. Studies indicate the systems' cavity gap may cause overheating problems in hot climate zones [4]. Shameri stated that this system shows optimum daylight performance in subtropical regions, among other climatic conditions [5]. However, the literature indicates that this façade system can provide optimum thermal and visual performance in different climatic zones with the proper design recommendations [6]. In Egypt, daylight optimisation of Mashrabiya façades, a traditional DSF system, increased the illuminance in the interior by 24% in a dry, hot desert climate (BWh) [7].



As in all buildings, the type of glass and the reflectance of interior surface materials impact the visual performance in buildings with DSF systems. Double-glazed photovoltaic (DGPV) glass reduces energy consumption compared to low-E glass. When the light transmittance of DGPV glass is 30-40%, visual and thermal comfort in the interior is at optimum level [8]. Polymer-dispersed liquid crystal (PDLC) film applications on glass surfaces allow daylight to enter the interior in a controlled manner. PDLC applications on glass surfaces reduce energy consumption by 10-15% [9]. TiO<sub>2</sub>@W-VO<sub>2</sub> thermochromic glass provides 18.6% solar modulation capability and 56% visible transmittance in a typical office [10].

Weather data is very significant in simulations according to building location. It provides information about, i.e., average surface and air temperatures. As the world's average surface and air temperatures are increasing due to greenhouse gas emissions and the climate crisis (CC) [11, 12,13], that leads to an increase in the energy required for cooling in the interior spaces of buildings. Thus, the European Union (UN) aims to reduce greenhouse gas emissions and energy demands [14].

The rise in air temperatures will cause overheating problems in the interior of buildings in the coming years. The increase in sunshine hours in the coming years will also affect the daylighting performance of indoor spaces. CCWorldWeatherGen and WeatherShift have created Toronto's weather scenario for the 2060s. As a result of energy simulations in the future weather scenario of 16 commercial buildings in this region, it is stated that the heating load will decrease by 17.9-33.4% in 2060 compared to 2014, while the cooling load will increase by 12.9-53.3% [15]. The simulation results using the future weather scenarios of Hong Kong determined that the annual cooling energy of a dwelling will rise to 278.80% [16].

Our study focuses on an office in an educational building in İzmir, Türkiye. The study initially performed on-site thermal and illuminance measurements for model calibration and validation. Ladybug and Honeybee conducted the simulation process. Meteonorm v8 created Izmir's near future (2050s) and far future (2080s) weather scenarios according to RCP4.5. In the simulation process, the study analysed the cooling energy throughout the year in 2050 and 2080 weather scenarios. The results of the simulations using 2050 weather scenarios show that the cooling energy requirement increases by 663.2% compared to the scenarios using 2025 climate data. The results of the simulations using 2080 weather scenarios show that the cooling energy requirement increases by 751.6% compared to the scenarios using 2025 climate data. To reduce this excessive rise in energy demand in the future, it is essential to create a scenario of changing weather conditions with the effect of CC and to develop designs according to these conditions.

Thus, this study aims to provide optimum visual comfort in the interior of an educational building with a DSF system for at least 50 years, optimising the cavity gap depth, floor, wall, ceiling reflectance, and window glass through a computational framework. Algorithms carry out the optimisation process. Genetic algorithms (GA) are computational optimisation methods that mimic the evolutionary process and focus on solving complex problems. The covariance matrix adaptation evolution strategy (CMAES) is also an evolutionary algorithm. This algorithm is based on repeated recombination, mutation and selection interactions. Different variations of individuals in generations are selected as parents for the next generation. Since the effectiveness of each algorithm in solving problems varies, this study used both algorithms in the optimisation process. The significance of this study is the integration of future weather scenarios in the optimisation process using Galapagos' Genetic Algorithm (GA) and Opossum's Covariance matrix adaptation evolution strategy (CMAES) algorithm to check better daylight performance. The study will guide designers dealing with an educational building with a DSF system in a CSA climate type within 50 years.

## 2. Computational Framework

The study focuses on the office with a DSF system located in the Civil Engineering building of Ege University in Izmir. The study first performed in-situ illuminance measurements to determine the accuracy of computational optimisations. Building a parametric model in Rhino/Grasshopper is the second stage of the study. Ladybug and Honeybee daylight and energy simulations were performed in the third stage. The model calibration process compares on-site measurements and simulations of the

current situation. Since the study will provide design recommendations for the near and distant future, Meteornorm produces future weather scenarios for Izmir. Opossum and Galapagos use epw weather files prepared by Meteornorm in the optimisations. Figure 1 shows the study workflow.

Opossum and Galapagos carry out the optimisation process. CMAES (Covariance Matrix Adaptation Evolution Strategy) is a type of algorithm of Opossum to focus on difficult non-linear non-convex black-box optimisation problems and GA (Genetic Algorithm) is a type of adaptive heuristic search algorithm of Galapagos to solve problems by natural selection and genetics idea [17]. The study tests the effectiveness of different algorithms in the optimisation process. Table 1 shows the design parameters optimised by the algorithms.

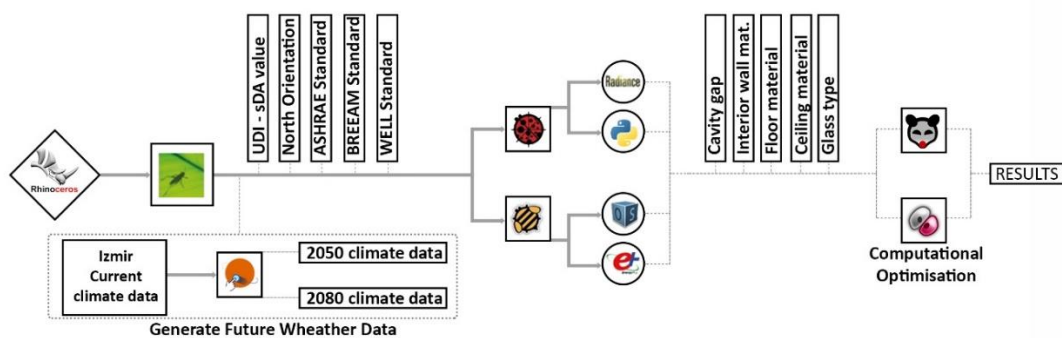


Figure 1. Workflow of the study.

Table 1. Optimised parameters.

Parameters	Explanation	Unit	Boundary
x1	Cavity depth	m	[0.4 – 1.10]
x2	Interior wall material	%	[0.10 - 0.99]
x3	Floor material	%	[0.10 - 0.99]
x4	Ceiling material	%	[0.10 - 0.99]
x5	Glass transmittance	%	[0.10 - 0.99]

Figure 2 shows the educational building with the DSF system, which is the subject of the field study. It shows (a) the relationship of this building with its surroundings, (b) the external view of the office with the DSF system, and (c) the plan of the office with the DSF system. The depth of the office with the DSF system is 3.75 m., and the width is 3.15 m. The floor height of the south-orientated office is 3.10 m.



Figure 2. (a) Location, (b) South and façade of the educational building with DSF system, (c) plan of office with DSF.

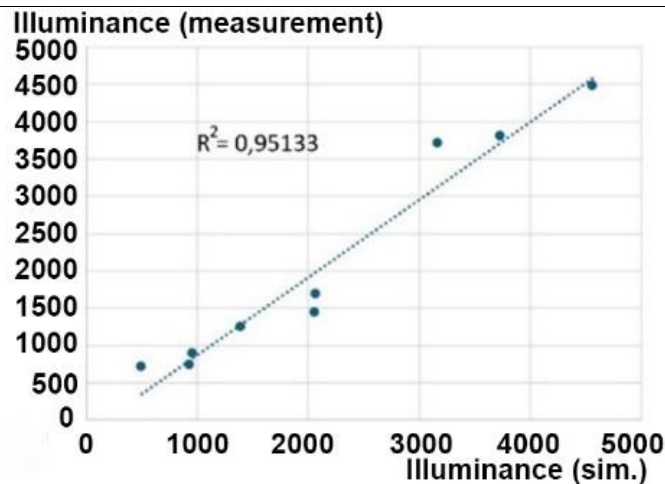
### 3. Findings

The study compared the average in-situ illuminance at 9.30, 12.30, and 15.30 on 21 March 2022 under clear sky conditions at the office with the DSF system at Izmir Ege University with the model's

illuminances on this date for model reliability (Table 2). Figure 3 shows the Ladybug model's coefficient of determination ( $R^2$ ). The figure shows that the model is 95% consistent with the actual data.

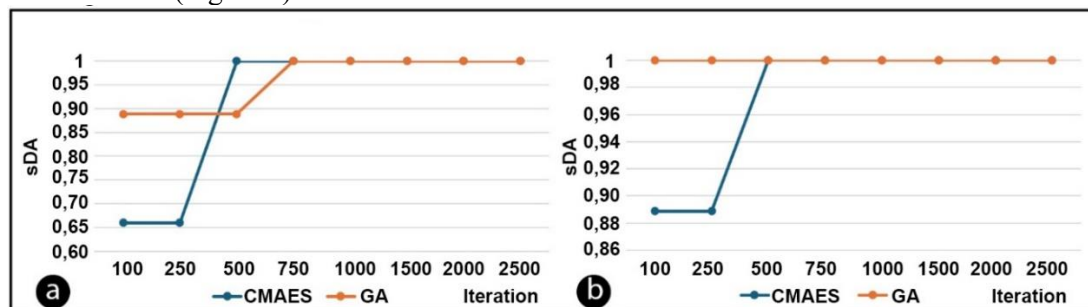
**Table 2.** Measurement points and Ladybug output values (S: Simulation, M: Measure).

	1	2	3	4	5	6	7	8	9
<b>S</b>	4568	3736	3169	2072	2061	1399	960	932	501
<b>M</b>	4475	3797	3704	1678	1440	1249	880	741	702



**Figure 3.** Scatter plots of Ladybug simulation and measurement values.

In the optimisations using the 2050 weather scenario, CMAES achieved the best values (sDA 100%) in the first 500 iterations and GA in the first 750 iterations. In the optimisations using the 2080 weather scenario, GA achieved the best results in the first 500 iterations, and CMAES achieved the best in the first 100 iterations (Figure 4).



**Figure 4.** Convergence graphs for the best optimisation results in 2050 (a) and 2080 (b) weather scenarios.

Figure 5 shows the model proposals of CMAES and GA that provide the optimum visual performance for Izmir's 2050 and 2080 weather scenarios. The cavity gap depth of the model proposals resulting from the optimisations using CMAES, 2050 and 2080 weather scenarios is 0.61 m. The cavity gap depth of the GA's model proposal in the result of the optimisation using the 2050 weather scenario is 0.49 m, while the cavity gap depth of the optimisation using the 2080 weather scenario is 0.56 m. In the optimisations of GA, the cavity gap depth increased by 0.07 m in 30 years. Using 2050 weather scenarios, CMAES obtained the reflectivity of the surface materials in the range of 0.8-0.9, while GA obtained the reflectivity in the range of 0.3-0.05. Using 2080 weather scenarios, CMAES obtained the reflectivity of surface materials in the range of 0.7-0.9 and GA in the range of 0.3-0.4. There is a significant difference between the surface reflectivity of the proposed models due to the optimisations

of CMAES and GA. However, the surface reflectivity of these algorithms did not change significantly over time.



Figure 5. Comparison of proposed models in Izmir 2050 and 2080 weather scenarios.

The study used spatial daylight autonomy (sDA) —annual measure of daylight sufficiency based on percentage of floor area and annual sunlight exposure (ASE) annual measure of excessive direct sunlight which may cause glare, based on percentage of floor area for daylight assessment. sDA defines the area where a light level of 300 lx is achieved in at least half of the space, while ASE indicates that a light level of 1000 lx in more than 10% of the space, causing visual discomfort. Ladybug achieved 66.67% annual ASE and 100% sDA due to daylight simulation of the office with the existing DSF system. The WELL standard recommends ASE of less than 10% and sDA of greater than 55% for optimum visual performance indoors. Honeybee calculated that the heating energy per m<sup>2</sup> of the office with the existing DSF system is 26.10 kWh while the cooling energy is 2.50 kWh. In the future, the increase in air temperatures due to the CC effect will negatively affect energy consumption. The study compared the total energy consumption in the current situation with the total energy consumption in Meteonorm's 2050 and 2080 weather scenarios for Izmir. In 2050, cooling energy increased by 663.2%, and heating energy increased by 100.2% compared to current conditions. In 2080, cooling energy increased by 751.6%, and heating energy increased by 108.3% compared to the current conditions. The study also compares the energy performance of the existing and proposed models.

Table 4 shows the daylighting metrics and heating and cooling values per m<sup>2</sup> of the proposed models obtained due to the optimisation of CMAES and GA. In the near and far future, the amount of heating energy in the proposed models will be below the current energy consumption values of the current model, while the amount of energy required for cooling will be above the current data.

Table 4. Daylight metrics and energy consumption values of optimised models.

	CMAES				GA			
	sDA	ASE	Heating (kWh/m <sup>2</sup> )	Cooling (kWh/m <sup>2</sup> )	sDA	ASE	Heating (kWh/m <sup>2</sup> )	Cooling (kWh/m <sup>2</sup> )
<b>2050 WS</b>	1.0	6.7	22.75	5.25	1.0	7.11	21.33	5.34
<b>2080 WS</b>	1.0	7.77	20.80	4.27	1.0	6.66	20.98	4.63

#### 4. Conclusion

Studies in the literature on the climatic suitability of DSFs have determined that this façade system shows optimum visual and thermal performance in cold climate types. However, studies show that buildings with DSF systems that exhibit optimum visual and thermal performance in hot climates can also be recommended by taking the proper design measures. The further increase in air temperatures due to the CC effect in hot climate types may prevent the designs from providing optimum performance in the near and distant future. For this reason, the study has created near and far future weather scenarios of Izmir, which shows the characteristics of the CSA climate, which is a hot climate type, and used these weather scenarios in the optimisations.

Opossum's CMAES and Galapagos' Genetic Algorithm independently conducted the optimisation process in 50 populations and 50 generations using near and far future weather scenarios. This process aimed to achieve maximum sDA and minimum ASE. As a result of the optimisation processes, the cavity gap depths are not significantly different. In addition, the energy consumption for heating of the proposed models at the end of the optimisation process is reduced by 12-20% compared to the existing model. The study guides designers in determining the cavity gap depth and surface material for educational buildings with DSF systems that will be applied in CSA climate type and provide optimum visual performance for 50 years.

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